Associations of turbidity and diet in smallmouth and spotted bass and creek chubs of the Scioto River Basin, OH: A preliminary assessment

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Chapter 1: Background and Literature Review

Supply and Transport of Sediment in Streams and Rivers

Sediment in Streams

Sediment enters streams from both natural and anthropogenic causes by way of bank erosion and runoff from the landscape (see Sullivan and Watzin 2010). Recent increases in the amount of stream sediment are largely due to runoff from agricultural fields (Walser and Bart 1999). Once sediment enters a stream, is it classified by its source or how it is transported. Source is separated into suspended and bed load. The transported load is further broken down into washload and bed material load (Figure 1).

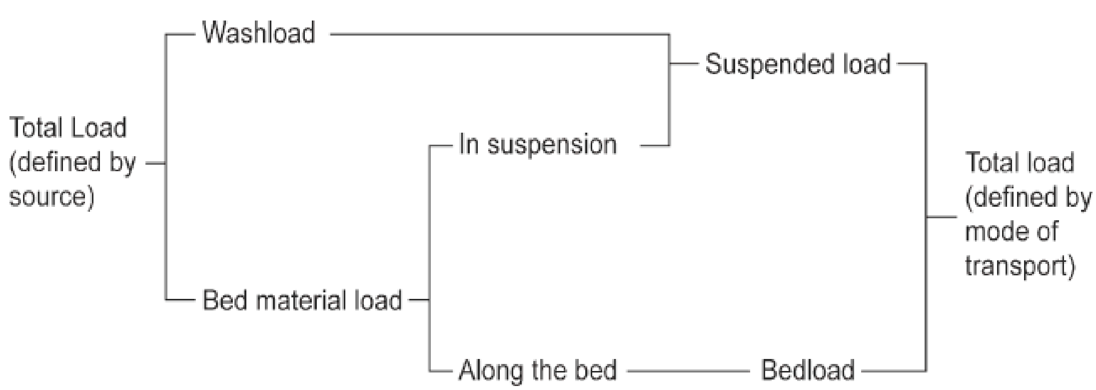

Figure 1. Total sediment load and its constituent components, as described by Hicks and Gomez (2003) in Allan and Castillo (2007)

All loads, whether bed, suspended or wash, are transported downstream. The distance that a load will travel is dependent on a number of characteristics of both the particle and the stream. This is expressed as an equation in Lane's Law,

$$Q_s * D_{50} = Q_w * S \qquad (1)$$

where Q_s is the sediment discharge, D_{50} is the mean particle diameter, Q_w is water discharge and S is the slope of the stream. Sediment discharge is the amount of sediment that the stream transports and water discharge is the volume of water that flows past a certain point within a given time (Lane 1955 in Allan and Castillo 2007). As water velocity decreases, larger particles settle out while the smaller particles continue to travel downstream. The decreased flow and subsequent particle settling constitutes a decrease in transport capacity of the system since fewer particles are able to be transported (Allan and Castillo 2007).

Source Load

Wash load and bed material load constitute the principal components of source load. As the name suggests, washload is sediment in the stream entrained from the landscape. It is made up of particles that are suspended in the stream and the particles are between very fine sand and clay sizes (see Table 1). Due to the small size of wash load particles, only a slow flow is needed to keep them in suspension, and they may never settle out (Hicks and Gomez 2003 in Allan and Castillo 2007). Bed material load is made up of sand to gravel sized particles picked up from the stream bottom and transported further downstream (see Table 1). This load source requires a higher flow velocity than the wash load and is directly related to the transport capacity of the system (Hicks and Gomez 2003 in Allan and Castillo 2007).

Particle Category	***Size Range (mm)***
Boulder	>256
Cobble	64-256
Large	128-256
Small	64-128
Gravel	2-64
Very Coarse	32-64
Coarse	16-32
Medium	8-16
Fine	4-8
Very Fine	2-4
Sand	0.0625-2
Very Coarse	1-2
Coarse	0.5-1
Medium	0.25-0.5
Fine	0.125-0.25
Very Fine	0.0625-0.125
Silt	<0.0625

Table 1. The Wentworth Grain Size scale. Bold categories are general descriptions of size. Italics are broken down into more detailed groupings.

Transport Load

The transport load is separated into suspended and bed load. This refers to the location in the stream in which sediments are principally carried: the suspended load in the water column and the bed load along on the stream bottom. Suspended load either enters the stream from runoff during storm events or is picked up off of the bottom by eddies and turbulence. These particles are swept up into the water column and carried until the flow velocity subsides and they settle out (Hicks and Gomez 2003 in Allan and Castillo 2007). Bed load are particles that are also moved by eddies and turbulence that skip or roll along the bottom and never enter the water column. These are the last to start moving downstream and the first to downstream movement (Allan and Castillo 2007).

Effects of Suspended Load

Suspended load accounts for the majority of sediment transport, and it has a number of effects on organisms, both while it is in the water column and when it settles to the streambed. While sediment is in the water column, it causes an increase in turbidity or water cloudiness (Melo et al. 2009). When fine particles such as silt and clay settle, siltation and increased embeddedness occur. Siltation is the process of fine particles covering the previous substrate (Sutherland et al. 2002). Embeddedness is a direct effect of siltation and is the amount of a substrate that is covered by silt or clay (Sutherland et al. 2002).

Sedimentation and Stream Impairment

The United States Environmental Protection Agency (USEPA, 2010) has reported that the two most common non-point source pollutants to streams and rivers are nutrients and sediment. Half of all streams within the United States are impaired by excess siltation and suspended sediment (Walser and Bart 1999). In large part, increases in stream sediment loads are caused by land-use change from forests to agricultural fields (Scheurer et al. 2009; Walser and Bart 1999; Zawiski 2007). Many states, including Ohio, have set a total maximum daily load (TMDL) on sediment to help control stream sediment loads (Ohio EPA 1999; Vondracek et al. 2003).

Within Ohio, high sediment loads characterize a number of streams. One of these is the Scioto River, a tributary of the Ohio River. The Scioto Rivers has a drainage area of 16,879 km squared and flows into the Ohio River at Portsmouth, OH. The Ohio EPA divides the Scioto River into three sections: upper (mainly in Hardin, Marion, and Union counties), middle (primarily in Franklin, Pickaway and Delaware counties), and lower (majority in Pickaway, Fairfield, Ross, Pike and Scioto counties) (Ohio EPA 2011). The watershed of the Scioto River is predominately agriculture (See Table 2) (Ohio EPA 2011).

Table 2. Land use percentage as broken down by section and averaged for the Scioto River watershed. Data courtsey of the Ohio EPA (http://www.epa.state.oh.us/dsw/tmdl/monitoring.aspx).

Site	% Agriculture Crops	% Developed	% Forest	%Pasture
Scioto Upper	80	8	6	4
Scioto Middle	40	45	6	5
Scioto Lower	26	7.5	47	13
Scioto River	48.7	20.2	19.7	7.3

The Scioto River is 371 km long and flows through 31 counties of central and south Ohio (Ohio EPA 2011). The river provides drinking water for 20 cities including Columbus. Also, it has the largest diversity of fish and mussels of any other watershed in Ohio (ODNR 2011). The Scioto River is characterized by high levels of sediment, nutrients, hydro-modification, heavy metals, and organic pesticides (Scioto River Valley Federation 2011).

Geomorphology and Sedimentation

Globally, anthropogenic erosion and sedimentation have led to significant alterations in stream geomorphology, habitat, and ecology. The geomorphology of a stream can be changed by dams and channelization (Gore and Shields 1995). These hydrological modifications cause changes in sediment loading regimes. A dam will generally cause sediment to be deposited above it and make the substrate finer (Gore and Shields 1995). Channelization decreases habitat diversity, and channels are filled in with fine sediment (Gore and Shields 1995). These changes and subsequent increases in siltation and suspended sediment have a number of ecological effects. For example, increased embeddedness through siltation will cause the pools to become shallower and reduce habitat area and complexity

(Rusuwa et al. 2006). Once the suspended sediment settles out, it will embed other substrate types causing them to become unusable for many species (Sutherland et al 2002). Unusable substrate can lead to avoidance behaviors and change stream communities (Melo et al. 2009). Siltation can also lead to the smothering of insect larvae and eggs and alteration of benthic habitat (Berry et al. 2003; Scheurer et al. 2009; Sutherland et al. 2002).

Whereas siltation can bury organisms living on the substrate, suspended sediment can influence fish and other species living in the water column. High concentrations of suspended sediment can clog filtering and respiratory organs in fish and macroinvertebrates and lead to suffocation (Berry et al. 2003). High levels of turbidity caused by elevated levels of suspended sediment can lead to alterations in light, which can affect the abundances of macroinvertebrates in the drift and reduce predation risk from birds (Berry et al. 2003; Harvey and Railsback 2009).

Sediment-Fish Relationships

An increase in turbidity can also have a variety of effects on fish depending on the amount of sediment and the type fish species. The responses of fish to suspended sediment increases can be grouped into three categories: lethal, sublethal, and behavioral. Lethal effects are classified as delayed hatching, increased predation risk, reduced growth rates and severe habitat degradation, and have been reported to be as high as 20% for nonsalmonid species under high suspended sediment conditions (Vondracek et al. 2003).

Sublethal effects include: epithelia thickening, respiration impairment, reduced tolerance to other environmental stressors, increased stress, lower prey abundance, and reduced reactive distance to prey (Sullivan and Watzin 2010; Sutherland and Meyer 2007; Walser and Bart 1999; Zamor and Grossman 2007). Respiration impairment, epithelia and lower prey abundances for benthic insectivores and herbivores can reduce growth rates (Berkman and Rabeni 1987; Sutherland and Meyer 2007). Reduced reactive distance may also be expected to be greatest for species that are visual hunters. Visual hunters have been shown to be outcompeted by those that are adapted to more turbid conditions, and thus the species composition may change (Bonner and Wilde 2002).

Behavioral adjustments include avoidance and abandonment of cover, both of which lead to changes in the abundance and distribution patterns of species (Melo et al. 2009; Vondracek et al. 2003). As Sullivan and Watzin (2010) showed, fish (white suckers *Catostomus commersoni*, creek chubs *Semotilus atromaculatus*, and pumpkinseed sunfish *Lepomis gibossus*) will avoid areas that are subject to sediment build up due to a lack of cover and reduced food availability. Melo et al. (2009) showed a similar trend for four Cynodontidae species (*Hydrolycus armatus, Hydrolycus tatauaia, Rhaphiodon vulpinus,* and *Cynodon gibbus)* that avoided areas with higher levels of turbidity because they are visual hunters. Berkman and Rabeni (1987) investigated the effect of siltation on a fish community in northeast Missouri. These workers divided the fish into different feeding and reproductive guilds and assigned them habitats based upon distribution. They found that some fish feeding and reproductive guilds were negatively affected by increases in siltation. For example, benthic insectivores and herbivores became less prevalent as percent of fine sediments increased, but other feeding guild were unaffected. The simple-lithophilous reproductive guild, which requires clean gravel for spawning, was the most negatively affected by increases in siltation, although none reproductive guilds increased in abundance with higher turbidity levels (Berkman and Rabeni 1987).

Effects of Turbidity on Fish Diet

Numerous studies on a variety of species have shown that an increase in turbidity due to suspended sediment can decrease the reactive distance of a fish (Queensberry et al. 2007; Sweka and Hartman 2001 and 2003; White and Harvey 2001; Zamor and Grossman 2007). This reduced reactive distance has been shown to negatively affect the ability of some species to capture prey (Zamor and Grossman 2007). For example, foraging success of both the rosyside dace (*Clinostomus funduloides*) and the brook trout (*Salvelinus fontinalis*) decreased with increasing turbidity (Sweka and Hartman

2001; Zamor and Grossman 2007). Zamor and Grossman (2007) conducted reactive distance tests on rosyside dace in an artificial stream at two different temperatures in order to simulate seasons. The spring-autumn was 12 °C and the summer temperature was 18 °C. Rosyside dace experienced a decrease in foraging success at all turbidities (0-56 NTU) and temperatures. While both temperature and turbidity had an effect on the foraging and prey capture success of the rosyside dace, there was no significant interaction between the two variables (Zamor and Grossman 2007). In a similar experiment with brook trout, Sweka and Hartman (2001) found that its reactive distance and prey detection decreased with higher levels of turbidity. However, once detected, the probability that the prey would be captured and ingested was independent of turbidity (Sweka and Hartman 2001). In addition, even though capture and ingestion rates remained the same, the reduced reactive distance causes a decrease in the drift foraging success of brook trout (Sweka and Hartman 2001).

Certain fish species may have the ability to locate prey using non-visual cues. For example, Harvey and Railsback (2009) using a spatially explicit individual-based model to examine the persistence of trout in more turbid systems discovered that coastal cutthroat trout (*Oncorhynchus clarkii)* have the ability to use non-visual cues to locate prey. In that study, turbidity was assumed to reduce a fish's risk of predation and reactive distance to drift-prey. This model estimated that if predominantely drift-feeding coastal cutthroat trout were subjected to high turbidity regimes they would become extinct in 15 years. This is not the case as cutthroat trout have been living in under higher turbidity regimes for longer than 15 years. This suggests that cutthroat trout have the ability to use non-visual cues in highly turbid systems to locate prey even though they are primarily visual hunters (Harvey and Railsback 2009).

Rainbow trout (*Oncorhynchus mykiss*) also were shown to locate benthic prey during periods of high flow and turbidity using non-visual clues (White and Harvey 2007). These non-visual cues are more common if the species are adapted to higher turbidity regimes. Bonner and Wilde (2002) found that two of these turbidity adapted fish, the peppered and flat head chub *(Macrhybopsis tetranema* and

Platygobio gracilis), had a smaller prey consumption loss with increasing turbidity, as measured along a gradient of 0-4,000 NTU (nephelometric turbidity units), compared to species that were clear-water adapted (e.g., Arkansas river *Notropis girardi*, emerald *N. atherinoides*, red *Cyprinella lutrensis*, and sand *N. stramineus* shiners). The pre-consumption loss was only 21% and 26%, respectively, compared to >73% for the clear water fish. When the water is clear, however, these visually hunting species have been shown to be competitively superior to those that are adapted for turbid water (Bonner and Wilde 2002).

Study Species

Creek Chubs (Semotilus atromaculatus)

Creek chubs are in the minnow family (*Cyprinidae*) and are widely distributed across Ohio (Ohio Department of Natural Resources 2010). Their optimal habitat is a defined riffle-pool structure with clear water (McMahon 1982). Though clear water is preferred, they may tolerate turbid waters. However, high levels of sedimentation have been shown to have a negative impact upon the health of an individual creek chub if it is prolonged (Sullivan and Watzin 2010). Creek chubs are best recognized by a black spot at the base of the dorsal fin and on the base of the tail, and they also have a flat head, large mouth and a stripe across the middle of their body (Figure 2) (Troutman 1981).

One potential reason that creek chubs are considered fairly tolerant to changes in water quality is because of their opportunistic diet. As juveniles they primarily feed on aquatic and terrestrial insects, while the adults also consume mollusks and fish. During the summer months,

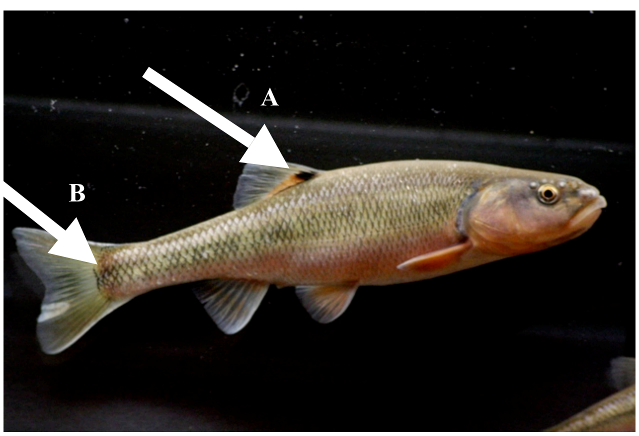

Figure 2. Picture of a creek chub (*Semotilus atromaculatus*) with identifying characteristics. 'A' points to the black dorsal fin spot; 'B' points to the spot at the base of the tail. Photo courtesy of the Ohio Department of Natural Resources: (http://www.dnr.state.oh.us/Home/species_a_to_z/SpeciesGuideIndex/creekchub/tabid/6599/Default.aspx).

individuals over 80mm in length will predominantly feed on smaller fish (McMahon 1982). Creek chubs are visual scavengers that feed on a variety of food items within the water column. They are surface and water column feeders that visually locate prey, and thus, this study hopes to determine if variability in turbidity significantly alters the creek chub diet.

Individual creek chubs reach sexual maturity between the ages of 2 and 5 years, corresponding to a length of 100 - 200 mm. Once mature, the male will construct a nest in gravel at the foot or head of a riffle. Spawning occurs in the spring between April and July at water temperatures above 14 ºC (McMahon 1982). The most important factors for egg survival are temperature, turbidity, and flow conditions. Embryos need temperatures between 13 and 20 ºC, and flow velocities of 20 to 64 cm/s. The survival of eggs laid in silt and sand is essentially nil (McMahon 1982). Once hatched, the fry move to faster flowing water and feed on aquatic and terrestrial insects and amphipods.

Spotted Bass (Micropterus punctulatus):

Spotted bass are in the sunfish family (*Centrarchidae*) and are a common sport fish in Ohio and elsewhere. They are commonly mistaken for largemouth bass, but have some distinguishing features (Figure 3). When a spotted bass's mouth is closed it ends at the edge of the eye. Spotted bass typically also have red or brown eyes compared to the yellow of largemouth bass. Finally, the spotted bass have spots or stripes on the lower half of its body (Figure 3) (Troutman 1981).

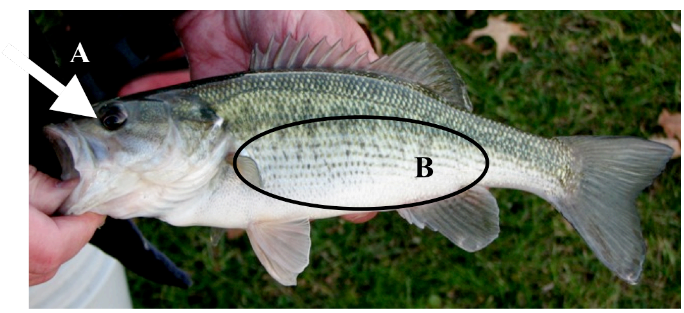

Figure 3. Spotted bass (*Micropterus punctulatus*) with some identifying characteristics labeled. ‘A’ points to the red eye color;‘B’ circles the black spots on the lower half of the fish. Photo courtesy of the Ohio Department of Natural Resources: (http://www.dnr.state.oh.us/Home/species_a_to_z/SpeciesGuideIndex/spottedbass/tabid/6765/Default.aspx).

Spotted bass live in both rivers and large reservoirs. In rivers, they prefer deep pools and well-defined riffles with a rocky substrate with a moderate flow. Turbidity level is generally not a determining habitat factor for this species when in rivers (McMahon et al. 1984). In reservoirs however, turbidity, substrate type and fertility are the most important factors. The optimal reservoir habitat is clear deep water with a rocky substrate. Clear water is preferred since the spotted bass is an ambush predator. Spotted bass have an optimal environment with turbidities less than 60 NTU, though they can survive in more turbid conditions (McMahon et al. 1984). The rocky substrate is used for breeding as well as habitat for their prey species, crayfish and fish (McMahon et al. 1984). Spotted bass avoid mud, dense vegetation, and fast current. Spotted bass prefer cover and will congregate around man-made structures that add to cover in open water (McMahon et al. 1984).

Spotted bass fry feed on phytoplankton as well as aquatic and terrestrial insects. The diet of individuals greater than 75 mm total length is large aquatic and terrestrial insects, fish and crayfish depending on the location of their habitat and the season. The predominant food source is crayfish, and it has been shown the abundance of crayfish affects the abundance of spotted bass (McMahon et al. 1984). Spotted bass are visual hunters that ambush their prey. Therefore, this species relies upon the clarity of the water to hunt, and elevated turbidity will affect their ability to hunt successfully. This makes spotted bass a good species to test the hypothesis that feeding success varies as a function of turbidity since they may not be able to ambush their prey as effectively due to a decreased reactive distance.

Spotted bass reach sexual maturity between the ages of 2 and 4 years for both females and males. Males and females move into the tributaries of larger rivers in order to spawn. Spawning occurs in the spring during April and May. The nests are built on firm substrate by cover such as brush or woody debris and are guarded by the males until the hatched fry disperse. Peak spawning occurs at temperatures between 18 and 21 ºC (McMahon et al. 1984).

Smallmouth Bass (Micropterus dolomieu)

Smallmouth bass in the family *Centrarchidae* and are a common sport fish in Ohio. As the name suggests, the mouth of this species is smaller than that of any other basses, extending only to the middle of the eye (Figure 4A). Another way to differentiate this species is the brown coloration and the vertical stripes, compared to largemouth and spotted bass which have an olive green color with a horizontal stripe down the side of the fish (Figure 4B) (Troutman 1981).

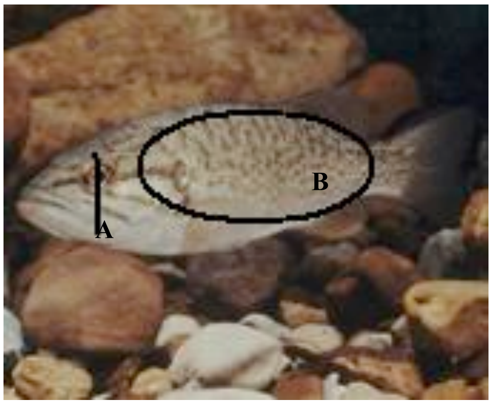

Figure 4. A photo of a smallmouth bass with some identifying characteristics labeled. "A" is from the edge of mouth to the eye. "B" circles the vertical stripes. Photo courtesy of Ohio Department of Natural Resources: (http://www.dnr.state.oh.us/Home/species_a_to_z/SpeciesGuideIndex/smallmouthbass/tabid/6756/Default.aspx)

In a tributary to the Illinois River in Oklahoma, Remshardt and Fisher (2009) observed that adult smallmouth bass prefer stream habitats with a flow velocity of 10-30 cm/s and pool depths of 55-155 cm. This species lives around large gravel substrate and uses root wads for cover. Young of year (YOY) smallmouth prefer depths of 35-115 cm and flow conditions of 25-80 cm/s. The YOY stayed near medium sized gravel and undercut banks and vegetation for protection and food availability. Neither YOY nor adults lived above a clay, detritus or vegetative substrate. At these two life stages, smallmouth bass used a wide variety of covers, but both avoided fractured bedrock substrate. Unlike the YOY, adults did not utilize the aquatic vegetation (Remshardt and Fisher 2009). In all life stages, smallmouth bass display strong cover seeking behavior and prefer protection from the light (Edwards et al. 1983).

Smallmouth bass can tolerate short periods of elevated turbidity, but are rarely found in areas with turbidities above 75 NTU, except during flood conditions. Smallmouth bass prefer 25 NTU or less since they are visual predators that ambush their prey (Edwards 1983). Smallmouth bass prefer a cooler environment and can live within 6-32 ºC, though 26-29 ºC is optimal for growth (Edwards 1983).

Easton et al. (1983) found that juvenile smallmouth bass (27.7-107.7mm total length) feed primarily on benthic macroinvertebrates in the New River in West Virginia. The dominant portion of their diet was Ephemeroptera, with Chronomidae, Amphipoda and Isopoda making up the rest of the diet. Trichoptera were avoided by smallmouth bass at all sites for the three years of the study (Easton et al. 1996). Adult smallmouth feed on crayfish and suitable sized fish due to gape limitation (Edwards et al. 1983). As with spotted bass, smallmouth bass are visual, ambush predators. This species was used in the present study because it has two predominant prey types that are found in different locations in the water column: crayfish are found on the substrate and prey fish (such as minnows) which are found in the water column.

Once smallmouth bass reach sexual maturity, males between ages 2 and 4 years and females between ages 2 and 5 years, they find a clean rocky or gravel substrate and the females lay their eggs. The males guard the eggs until they hatch. Spawning occurs in the spring, between mid-April and early July depending upon the latitude. The spawning temperature is 12-21 ºC with most of the activity occurring at temperatures warmers then 15 ºC (Edwards et al. 1983).

The most important factor in year class strength for smallmouth bass is the condition of the nest site habitat. Nests are usually built in shallow water with little or no current on rocky substrate. About 6ppm of dissolved oxygen is needed for maximum embryo survival with stable water levels (Edwards et al. 1983). The fry grow fastest in temperatures between 25-29 ºC. They eat zooplankton and live in calm shallows with rocks and vegetation for cover (Edwards et al. 1983). Once the fish reach the juvenile life stage, they move into deeper water with slower currents (Edwards et al. 1983).

Study Rationale

With half of the streams in the US suffering from excess sedimentation, it is important to understand the effects of increased sediment loads on fish. Fish are very important to an ecosystem structure and function, as well as, both commercial and recreational fishing (ODNR 2010). For example, detritivores, such as gizzard shad (*Dorosoma cepedianum*), can alter nutrient dynamics in reservoirs (Vanni et al. 2005). Alternatively, piscivorous fish, such as Atlantic cod (*Gadus morhua*), can control an ecosystem through ‘top-down’ effects and trophic cascades (Frank et al. 2005).

Overall, this research was guided by the following questions: (1) does turbidity affect the diet of visual hunting fish and (2) does turbidity alter fish feeding behavior? From these questions it was hypothesized that increases in turbidity would yield an increase in the amount of benthic prey consumed. The present study was conducted as a preliminary component of a larger study investigating the potential effects of sedimentation on the trophic ecology of stream fish. As such, this study was not designed to fully answer the questions, but rather to provide some initial findings related to the effects of turbidity on fish diet and trophic information at a subset of study sites.

Chapter 2: Research Chapter

Abstract

The primary objective of this study was to examine the effects of turbidity on fish diet and condition. In order to do this, eight stream reaches (i.e., study sites) were selected in two streams of different sizes (small stream – Slate Run, large river – Scioto River). At each study site, measurements of turbidity were recorded at multiple locations. From small stream sites, creek chubs (*Semotilus atromaculatus*) were collected for gut content analysis to explore potential differences in diets and fish condition among turbidity levels. Likewise, smallmouth bass (*Micropterus dolomieu*) and spotted bass (*Micropterus punctulatus*) were collected from the Scioto River and subsequently analyzed. Using a combination of t-tests, correlation, and regression analyses (including potential non-linear responses), differences in turbidity among sites and the potential effects of turbidity on dietary composition were investigated. Turbidity between small stream and large river sites was compared using a t-test and found to have significant variation ($\alpha = 0.05$). Fish condition, as determined by Fulton's Condition Factor, had a cubic relationship with turbidity and explained 98.8% of the variation in condition. Although this study was constrained by a small sample size and limited temporal variability in sampling, there was evidence that turbidity levels affect prey type. Turbidity accounted for 75.4% of the variation of crayfish being consumed, and smallmouth bass ate significantly more of this prey item than the other two study species. Overall, the three main prey sources (fish, crayfish, and aquatic insects) had a positive linear relationship with turbidity. This study provides important preliminary information for the effects of turbidity on stream fish condition and diet, and is expected to help inform larger efforts in the region related to land use and riverine food webs.

Introduction:

According to the US EPA, one of the two most prevalent nonpoint source pollutants to US streams and rivers is total suspended sediment (TSS; USEPA, 2011). In a study by Walser and Bart (1999) in which 50 sites within the Chattahoochee River in Alabama and Georgia were surveyed, half of the sites were impaired by excess TSS from runoff. These increases in sediment loads were due to changes from secondary forests to agricultural fields and pastures (Scheurer et al. 2009; Walser and Bart 1999; Zawiski 2007). Excess TSS has become such a large problem that many states have set a total maximum daily load (TMDL) on TSS pollution that streams and rivers can receive (Ohio Environmental Protection Agency 2011; Vondracek et al. 2003).

Excess TSS causes increases in turbidity, which has a number of effects on fish and other aquatic life (Melo et al. 2009). Suspended sediment can clog gills and cause respiratory impairment and suffocation, reduced growth rates (in whitetail shiners, *Cyprinella galactura*, and spotfin chubs, *Cyprinella monacha*), and reduced tolerance to other environmental stressors (in non-salmonids) (Sutherland and Meyer 2007; Vondracek et al. 2003). When Sutherland and Meyer (2007) examined the effects of increased TSS on two species of minnow (whitetail shiners and spotfin chubs), they found that both growth rate and gill condition declined with increased TSS levels and duration of exposure. Vondracek et al. (2003) found a similar relationship between growth rates and TSS levels of non-salmonid species.

Aside from impacting the physical condition of the fish, numerous studies have shown that turbidity (a direct impact of TSS) also affects the ability of a fish to feed. Turbidity can directly affect fish feeding because of reduced visibility, which hampers visual hunting species more severely than non-visual species (Bonner and Wilde 2002). In particular, decreased visibility has been shown to strongly inhibit prey detection and reactive distance in the three-spined stickleback (*Gasterosteus aculeatus*), rosyside dace (*Clinostomus funduloides*), rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), and smallmouth bass (*Micropterus dolomieu*) (Queensberry et al. 2007; Sweka and Hartman 2001 and 2003; White and Harvey 2007; Zamor and Grossman 2007).

This study investigated the potential associations between turbidity and diet of creek chubs

(*Semotilus atromaculatus)*, smallmouth bass (*Micropterus dolomieu*), and spotted bass (*Micropterus punctulatus*). All three species are visual predators that live in the water column and are expected to be impacted by higher turbidity levels. Creek chubs eat a variety of food: aquatic and terrestrial macroinvertebrates, fish, and mollusks (McMahon 1982). Smallmouth and spotted bass consume insects, fish and crayfishes (Edwards et al. 1983; McMahon 1984). Since smallmouth and spotted are visual hunters and rely on a variety of food sources, it is expected that there will be a shift to a more benthic-rich diet in conditions of reduced visibility.

Since half of the streams in the US are impaired by excess sediment, it is important to understand the multiple effects that increased turbidity may have on fish (USEPA, 2011). Fish are important both on a commercial and a recreational level, and the study species are important to the recreational fishing industry (ODNR 2010). It is hoped this study will provide valuable preliminary information relative to the potential effects of turbidity on fish trophic ecology. Based upon the research for this study, it is hypothesized that an increase in turbidity will lead to increases consumption of benthic prey (for this study crayfish and some aquatic insects). Results of this study will be incorporated into a larger study examining how changes in land use and land cover (LULC) influence riverine food webs.

Methods

Study Sites

Two streams, one large and one small, were chosen for this study. The small stream Slate Run is a tributary of the large river studied, the Scioto River (Figure 5). Within each stream, four study sites (i.e., stream reaches) were selected in an attempt to represent a variety of turbidity levels. The sites on Slate Run were separated into two groups of two. One of these groups was at the Columbus Preparatory Academy and the other was in a neighborhood behind Littler Road. The two sites were divided into an upstream (top) and a downstream (bottom) site. The Scioto River sites were more widely distributed with sites occurring at South Bloomfield (upstream and downstream), Chillicothe and Piketon (Figure 5).

Figure 5. A map of Ohio with all eight sites marked and labeled. Scioto River site 5 is South Bloomfield Upstream, 6 is South Bloomfield Downstream, 7 is Chillicothe, and 8 is the site at Piketon. The image on the right-side is a close up showing the four sites taken from Slate Run in Columbus, Ohio. Slate Run site 2 is Academy Top, 1 is Academy Bottom, 3 is Littler Top and four is

Field Techniques

Fish Collection

Fish were collected in one of two ways depending on the type of the site, creek (Slate Run) or river (Scioto River). Fish from the four Slate Run sites (Figure 5) were collected using a Smith-Root backpack electrofisher (LR-24) following the methods summarized in Murphy and Willis (1996). Block nets were placed at both ends of the 30 m stretch to prevent immigration and emigration of the target species. The shocking wand was then moved upstream in a zig-zag pattern being sure to encompass as much of the stream as possible. All collected fish were identified to species. Six creek chubs from each site (89 to 161 mm in length) were immediately frozen for later analysis in the lab.

The fish from the four Scioto River sites were collected by boat electroshocking, also following Murphy and Willis (1996). The boat was moved downstream in a zig-zag pattern collecting all fish. Each site was shocked for 1 km (downstream of the entry point), and the collected fish caught were frozen and brought back to the lab for analysis. Spotted and smallmouth bass (142 -262 and 172 -274 mm in length, respectively) were then selected for gut content analysis.

Physical Measurements

At the Slate Run sites, pebble counts and estimates of percent embeddedness were carried out. Due to the depth and flow rate of the Scioto River, no pebble counts or % embeddedness measurements were conducted. For the pebble counts, the first 100 stones were collected randomly while looking away and then measured with a gravelometer following Wolman (1955). The pebble counts were completed across five transects with 20 stones being measured in each transect for a total of 100. This procedure was then repeated a second time for a total of 200 stones measured for each site. Each site had previous data (100 pebbles) that were also added into the count. Thus a total of 300 pebbles were used for all sites except Academy upstream. Permission to access Academy Top was denied when the 200 pebbles were counted, and thus this site only has the 100 stones from the previous data.

The % embeddedness was a visual estimate from riffles. Cobbles larger than 22.6 mm were randomly chosen and a visual estimate of the percent of it covered by silt. For each site that contained a riffle, 20 stones were chosen and percent embeddedness was recorded.

Turbidity Measurements

Turbidity measurements were taken either with a turbidimeter or through water collection and subsequent lab analysis. In the small sites, a summer turbidity reading was taken with a 6600 YSI multiprobe and in the spring readings were taken again, this time by collection bottle. The samples were collected using dark bottles from the center of the stream at three locations within each reach:

upstream, middle and downstream. These water samples were stored in a cooler before being tested. Samples were run on a Hach 2100N turbidimeter at the Ohio State University's Olentangy River Wetland Research Park. At the Scioto sites, the turbidity was only measured once in the spring with a Global Water WQ770 turbidimeter on range 1000 NTU, since the Scioto River typically has high turbidity and readings were taken at flood conditions due to a wet spring. Readings were recorded in order to encompass as much stream variability as feasible due to flood conditions and high water velocities. At Piketon and Chillicothe, turbidity readings were made (n= 9 and 8 respectively) on water from both banks as well as two samples from the floodplain (one on each side of the river). Due to a lack of access, only the left bank of South Bloomfield Upstream site was sampled, and no turbidity readings were collected from South Bloomfield Downstream.

Laboratory Techniques

Gut Content Analysis

Frozen fish were removed from the freezer and placed in a bowl of warm water to thaw for 24 hours. Guts were then removed via the methods detailed in Murphy and Willis (1996). An incision was made from the anus to the branchiostegal rays cutting through the pelvic girdle. Depending on the species, either the intestines (creek chubs) or the stomachs (smallmouth and spotted bass) were removed. The intestines were cut as close to the esophagus and anus as possible in order to gets much gut content as possible. The stomach was removed by cutting as close to the organ as feasible. The stomachs were then weighed with and without the food. The gut contents were removed using tweezers to pull out and the large pieces, and the rest was washed out with distilled water. Gut content items were identified to the lowest taxonomic level possible and stored in 70 % ethanol.

Numerical and Statistical Analysis

All results were analyzed using JMP © 9.0.0 Statistical Discovery Software (SAS Institute, Inc., Cary North Carolina). Data were transformed where necessary to meet conditions of normality and homoscadicity. A Student's t-test was conducted to compare turbidity levels between the Scioto River sites and the Slate Run sites. A correlation analysis was run in order to determine potential relationships among D_{50}, % embeddedness, and turbidity (at Slate Run sites only).

Fulton's Condition Factor is widely used as a measure of fish condition (see Sullivan and Watzin 2010). Fulton's Condition Factor was calculated by the formula in Murphy and Willis (1996):

$$(W / (L^3)) * 100{,}000 \qquad (3)$$

where W is weight of the fish in grams and L is fish length in millimeters. A regression was then run to explore the potential relationship between turbidity and Fulton's Condition Factor.

Variability in gut contents was evaluated through a regression analysis. The gut contents were separated by species. The main components of both the smallmouth and spotted bass stomachs were also compared graphically (Figure 8). The creek chub diet was broken into insect groups (% Diptera, % Formicidae, % other terrestrial insects and % aquatic insects) (Figure 9).

For creek chubs, the potential effects of turbidity on diet (% Diptera, % Formicidae, % other terrestrial insects and % aquatic insects) were investigated using regression analysis. For spotted and smallmouth bass the number of crayfish and fish eaten were analyzed against turbidity, also using a regression analysis. The gut contents were analyzed utilizing a Student's t-test to determine if stream size had an impact on prey consumption.

Results

Physical Parameters

The mean, standard deviation, minimum, maximum, and median of all the physical parameters (turbidity (NTU), D50 (mm), and % embeddedness) are presented in Table 3.

Table 3. The data from all sited within each stream was combined to give a mean, standard deviation (std dev), minimum, maximum and median o turbidity, D50 and % embeddedness.

		Mean	Std Dev	Min	Max	Median
	Turbidity	6.85	7.701	0	25.2	0.35
Slate Run	*Embeddedness*	28.813	29.406	0	90	20
	D50	43.746	40.465	0	200	32
Scioto River	*Turbidity*	162.871	124.93	24.28	337	97.5

The means were then used in subsequent analysis of the correlation between various physical parameters. A mulitvariate correlation with a scatterplot matrix and pairwise correlations was run. Correlations between D_{50} and turbidity (r =0.4139, p =0.5861), D_{50} and % embeddedness (r = 0.5344 and p = 0.4656), and turbidity and % embeddedness (r =0.3643 and p = 0.6357) were all non-significant.

Turbidity was graphed by site to look for patterns (Figure 6). Results from the t-test showed that turbidity levels were significantly different between Slate Run sites and Scioto River sites (t = -5.050 and p= 0.0020).

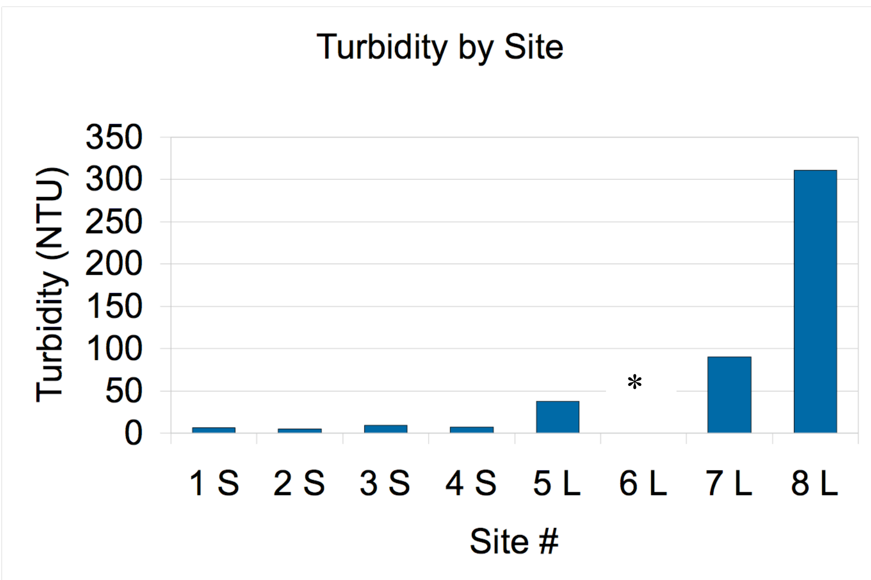

Figure 6. A graph that shows turbidity (NTU) by site numbers (from Figure 5). The S is for Slate Run sites and the L for Scioto River sites. It appears as though the larger sites have higher turbidity. * is South Bloomfield Downstream for which there is no turbidity data.

Turbidity and Fish Results

The three species observed in this study are creek chubs and smallmouth and spotted bass. As with the physical parameters the mean, standard deviation, minimum, maximum and median were taken by species of length, weight and

able 4. The mean, standard deviation (std dev), minimum, maximum and median of length (mm), weight (g), and Fulton's Condition Factor by specie ll creek chubs were collected from Slate Run and all bass were taken from the Scioto River.

		Mean	Std Dev	Min	Max	Median
	Length (mm)	112.5	20.426	89	161	108
Creek Chub	*Weight (g)*	15.771	9.589	8.1	40.9	12.6
	Fulton's Condition Factor	1.012	0.873	0.873	1.18	1.006
	Length (mm)	191.222	48.205	142	262	181
Spotted Bass	*Weight (g)*	86.229	86.229	42.3	271.7	71.8
	Fulton's Condition Factor	1.382	1.21	1.21	1.554	1.388
	Length (mm)	221.9	33.834	172	274	222
Smallmouth Bass	*Weight (g)*	182.67	94.239	74.1	346.7	156.95
	Fulton's Condition Factor	1.551	1.288	1.288	1.95	1.528

Fulton's Condition Factor (Table 4).

Turbidity explained 99% of the variation in Fulton's Condition Factor (cubic relationship: $F = 80.145$, $p = 0.0023$, $n = 7$) (Figure 7).

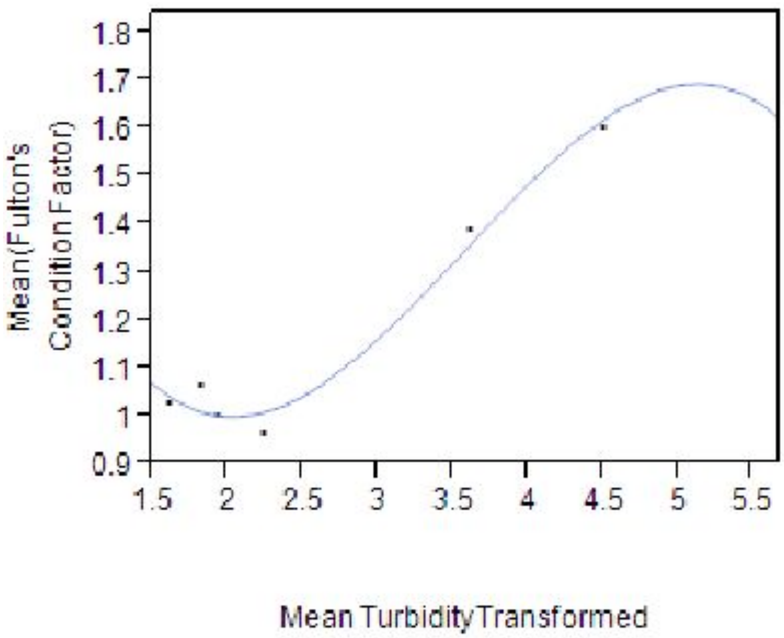

Figure 7. A cubic regression between turbidity (NTU) and Fulton's Condition Factor.

Fish Diet

Since the diet items are in different units, the major gut components were pulled out and placed into graphs so that differences can be seen visually. The graphs are broken into species and food item. The bass are in the same graph because both had crayfish and fish make up a major portion of their diet while insects made up most of the creek chub diet (Figures 8 and 9 respectively).

Figure 8. The major diet components of smallmouth (SMB) compared to spotted bass (SPB). Spotted bass eat an average of 1 fish and 1 crayfish while smallmouth bass consume an average of 1.5 crayfish and 1 fish.

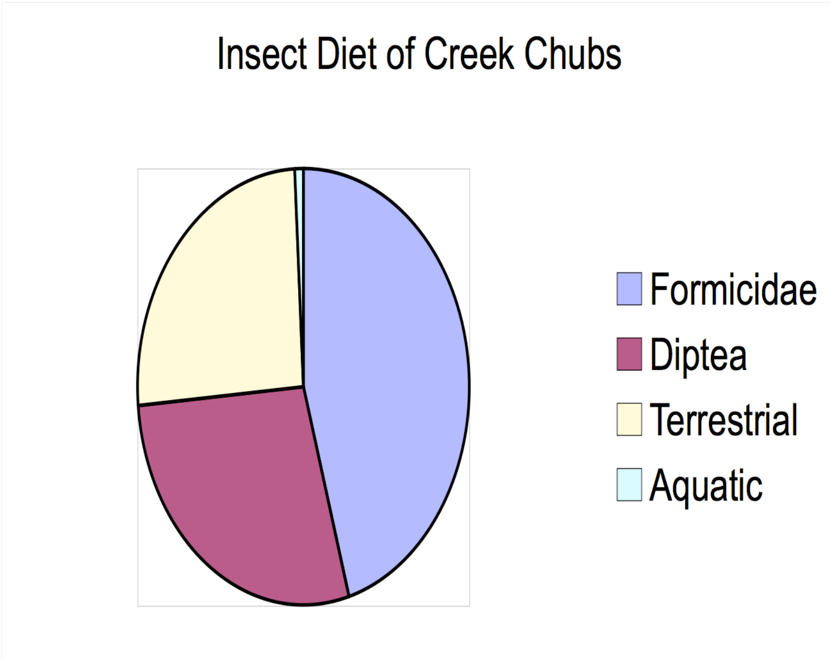

Figure 9. The relative average proportion of insects that make up a creek chub's diet. Averages are in percentages: % Formicidae= 24.67, % Diptera= 15.17, % other terrestrial insects=13.83 and % aquatic insects= 0.5.

The major gut content groups (average number of crayfish and fish eaten, % aquatic insects, and % Formicidae)were then compared to turbidity level and fish species. The % aquatic insects and the average number of fish and crayfish eaten had a significant linear relationship with turbidity (R^2 = 0.57, F = 6.64, p = 0.0496, 0, n = 7; R^2 = 0.58, F = 6.99, p = 0.0457, n=7; R^2 = 0.75, F = 115.39, p = 0.0111, and n=7 respectively). Only % Formicidae did not have a significant relationship with turbidity (R^2 = 0.88, F = 1.50, p = 0.548, and n=7) (See Figure 10). An oneway ANOVA was run on all of these groups to see potential variation among the species diets. There was no significant variation in the consumption of fish or % Formicidae (DF = 2, F = 1.31, p = .3287; DF = 2, F = 1.7350, p = 0.244). For % aquatic insects and crayfish a Tukey-Kramer HSD was run to see which species varied (DF = 2, F = 5.58, p = 0.0356, SPB = A, SMB = AB, CrC = B; DF = 2, F = 10.28, p = 0.0083, SPB = B, SMB = A, CrC = B). A t-test was run to investigate the effects of stream size on the consumption of prey items. There was no significant variation due to stream size upon the consumption of prey items: fish, crayfish, % aquatic insects and % Formicidae (t = -1.689, p = 0.130; t = -1.64, p = 0.1382; t = -2.004, p = .0799; t = 1.99, p = .0816 respectively).

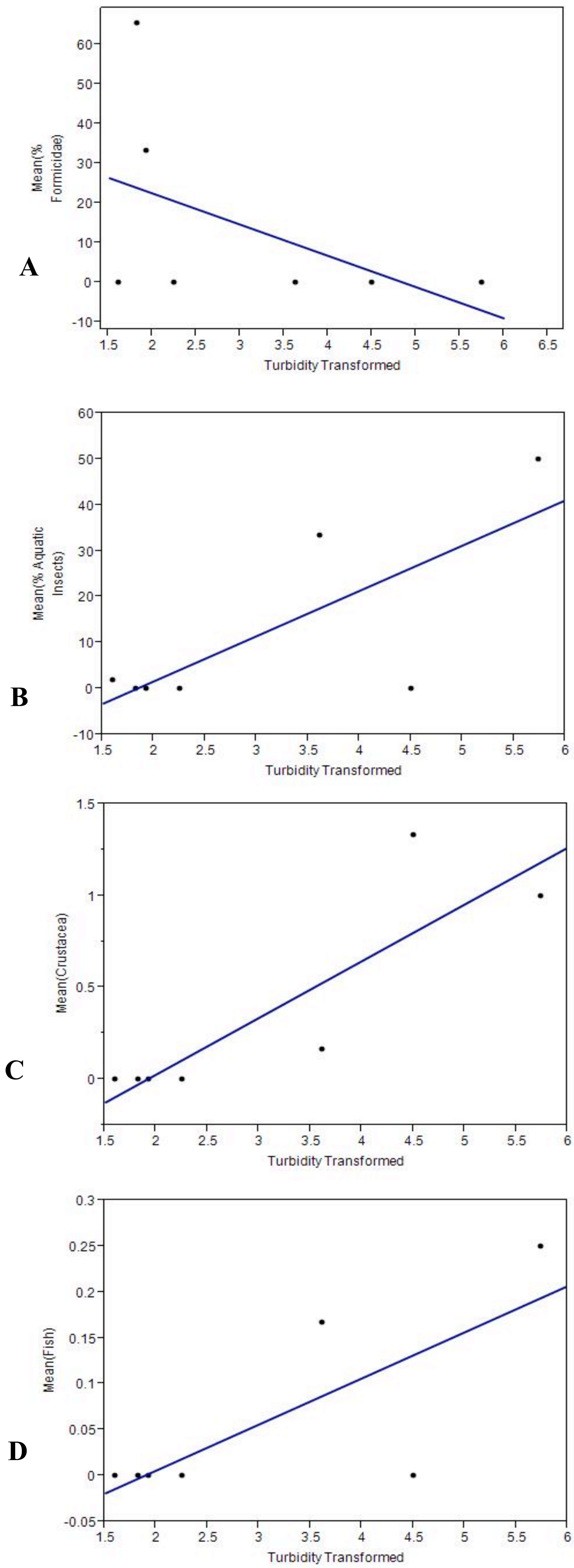

Figure 10. Regression analysis of turbidity log transformed and % Formicidae (A), Crustacea (B), Fish (C), and % aquatic insects (D). All of these regressions are linear and only % Formicidae is not significant.

Discussion

Overall, results from this study suggest that turbidity varies between the large and small streams and has an effect on diet composition (as determined by GCA) by encouraging a more aquatic-based diet. Although turbidity varied significantly between the sites, the consumption of crayfish, fish, % aquatic insects, and % Formicidae was not significantly different between Slate Run (small stream) and the Scioto River (large stream). The majority of variation between the amount of crayfish, fish % aquatic insects and % Formicidae ingested is explained by turbidity. Only % Formicidae did not vary significantly with turbidity. The other three prey items are aquatic obligates that live in different parts of the water column. Crayfish live on the substrate; fish are typically found in the water column, and aquatic insects are found in both the water column and on the substrate.

These findings relate to work done by Sullivan and Watzin (2010), Sutherland et al. (2002), and Zamor and Grossman (2007) among others. Sullivan and Watzin (2010) looked at the effects of turbidity on the condition factor of creek chubs, pumpkinseeds, and white suckers. Sutherland et al. (2002) found strong correlations between turbidity, % embeddedness, D_{50}, and land cover. Zamor and Grossman (2007) found that while both temperature and turbidity had an effect on the capture success of rosyside dace there was no significant interaction between the two variables.

Physical Parameters

The lack of correlation between turbidity, D_{50} and % embeddedness is surprising as is it commonly noted that these three parameters are related through hydrology (Rusuwa et al. 2006; Sutherland et al. 2002). Typically, TSS causes the turbidity and when it settles out it covers up the larger substrates thus simultaneously increases % embeddedness and decreases D_{50} (Sutherland et al. 2002). The lack of correlation in this study could be due to a low number of sites being observed – of the eight sites, only four had pebble counts and % embeddedness recorded. Since more sediment enters a stream during storm events, turbidity will vary temporally and be higher in seasons with greater rainfall, spring and autumn (Vanni et al. 2006). Unlike turbidity, D_{50} and % embeddedness do not vary seasonally, and this may account for the lack of correlation between the three.

The significant difference between turbidity in the large and small streams was expected. Larger rivers have a higher discharge and transport capacity, and thus can carry more sediment than smaller streams (Allan and Castillo 2007). Since they can carry more sediment on average, it is expected that they will consistently have higher turbidity levels, which was observed in this study. Also, the watershed of the Scioto River is heavily agriculture while Slate Run is more urban (Ohio EPA 1999). Land cover has a large impact on the amount of sediment entering a stream and most runoff comes from agricultural fields (Scheurer et al. 2009; Walser and Bart 1999).

Turbidity and Fish

The cubic relationship between Fulton's condition factor and turbidity level was a bit surprising.

Previous studies have shown that turbidity has a negative impact on the health of stream fish such as creek chubs (Sullivan and Watzin 2010; Sutherland and Meyer 2007). The data from this study points to a threshold point at which fish condition declines (Figure 7). In the study streams, this threshold may be the point at which the reduced water clarity begins to impair respiration and cause stress (Harvey and Railsback 2009). Vondracek et al. (2003) found threshold turbidity values change between species. A confounding variable in this explanation is that two different stream sizes were combined for this analysis, and there were few middle turbidity values. In the future, this experiment should be conducted across more turbidity levels in the same stream size to investigate potential threshold values.

Fish Diet

Variation among diets between the different fish species was only significant in % aquatic insects (between spotted bass and creek chubs) and crayfish (smallmouth bass was different from creek chubs and spotted bass). Creek chubs, in the lowest turbidity levels, did not appear to have changes in their diet based upon the available literature. Sullivan and Watzin (2010) and McMahon (1982) described creek chubs as water column and surface feeders. This explains the lack of aquatic prey sources in their diet, as they primarily eat at the surface, while smallmouth and spotted bass feed in the water column and on the substrate (Edwards et al. 1983; McMahon et al. 1984). Smallmouth bass ate more crayfish on average than either creek cubs or spotted bass. Crayfish, while not an important component of creek chub diets, are a large component of spotted bass so smallmouth eating more on average is surprising (McMahon 1982; McMahon et al. 1984). The higher average of crayfish being eaten by smallmouth bass could be a sign that smallmouth bass are out competing spotted bass. Long and Fisher (2005) found that when smallmouth bass are introduced to an ecosystem they expand and can displace spotted bass from their habitats.

The prey consumption was linear for all the three significant prey sources rather than the quadratic or cubic relationship that was hypothesized. However, turbidity was determined to have a significant impact on the number of crayfish, fish and the % aquatic insects eaten when all species were combined. Based upon the data presented in Figure 10, it appears that more fish, crayfish, and aquatic insects are eaten with increasing turbidity. Since fish, crayfish, and aquatic insects are common dietary components of the study species, it is possible that the observed turbidity levels do not affect their diets. Higher levels of turbidity may sufficiently hamper the ability to hunt visually, and thus a switch to non-visual cues could be initiated. White and Harvey (2007) found this phenomenon when they were studying rainbow trout and hypothesized that the fish were using non-visual cues to find benthic prey. The difference between fish, crayfish, and % aquatic insects could be a result of species variation. The only species caught at the site with the highest turbidity, Piketon, was smallmouth bass, which as stated above ate more crayfish on average than the other two species.

Conclusions

Sediment can have large impacts upon aquatic ecosystems, both when it is suspended in the water column and when it settles to the bottom (Rusuwa et al. 2006). Many of these effects are well documented, such as increases in turbidity and reduced reactive distance, but others need more research (Bonner and Wilde 2002; Melo et al. 2009). One of these is the effect of increased turbidity on the feeding behavior and diet of fish. This study focused on possible dietary shifts due to reduced water clarity on visual hunting species.

Over the course of this study, no strong dietary shifts were observed. Though as crayfish had the largest R^2 and the lowest p-value, it is possible that there may have been a switch to crayfish (a benthic prey item) at high turbidity levels. This trend, however, is confounded because only smallmouth bass were caught at the highest turbidity levels, and they ate more crayfish than the other two species. Additional research needs to be done in order to determine if this was a dietary shift or just a coincidence. More sites should be observed over a longer time span (a couple of years) to see if there is a trend towards a benthic-rich diet in waters with higher turbidity. However, this research provides valuable preliminary data that will help inform a larger study related to the effects of land use on riverine food webs.

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